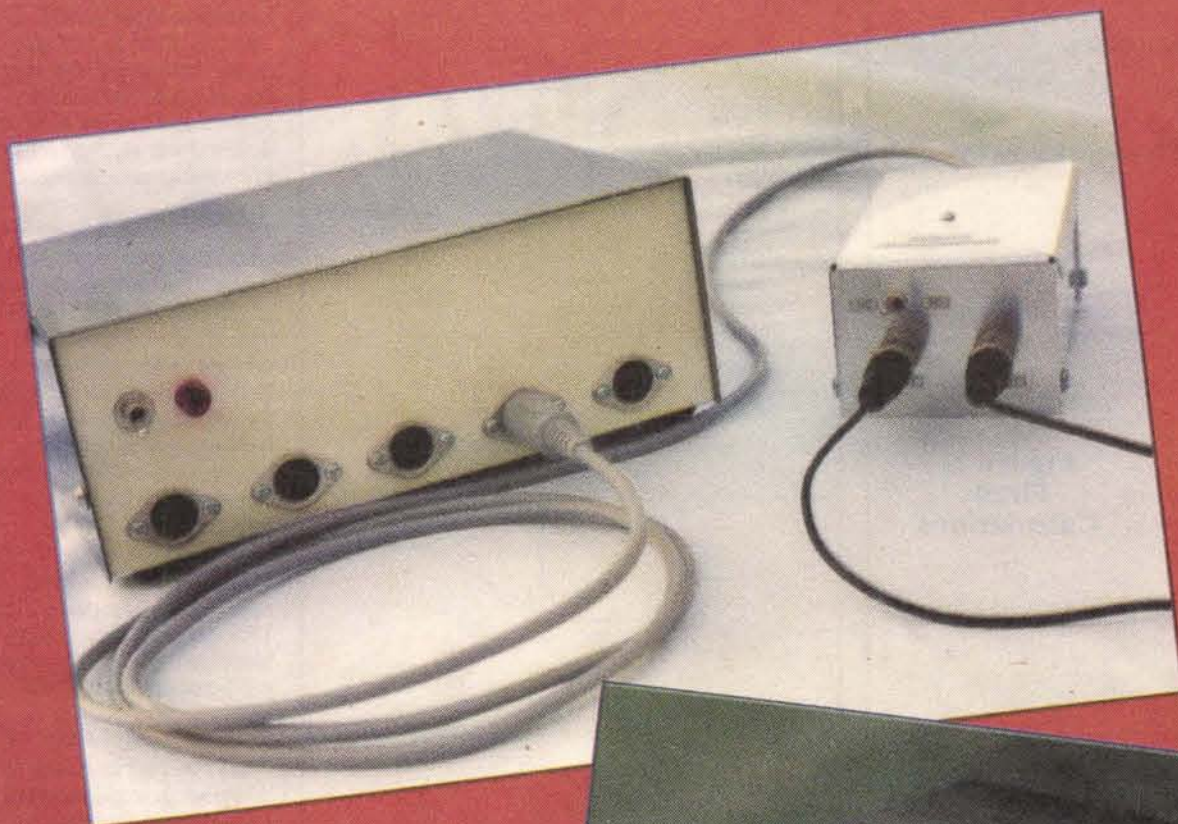
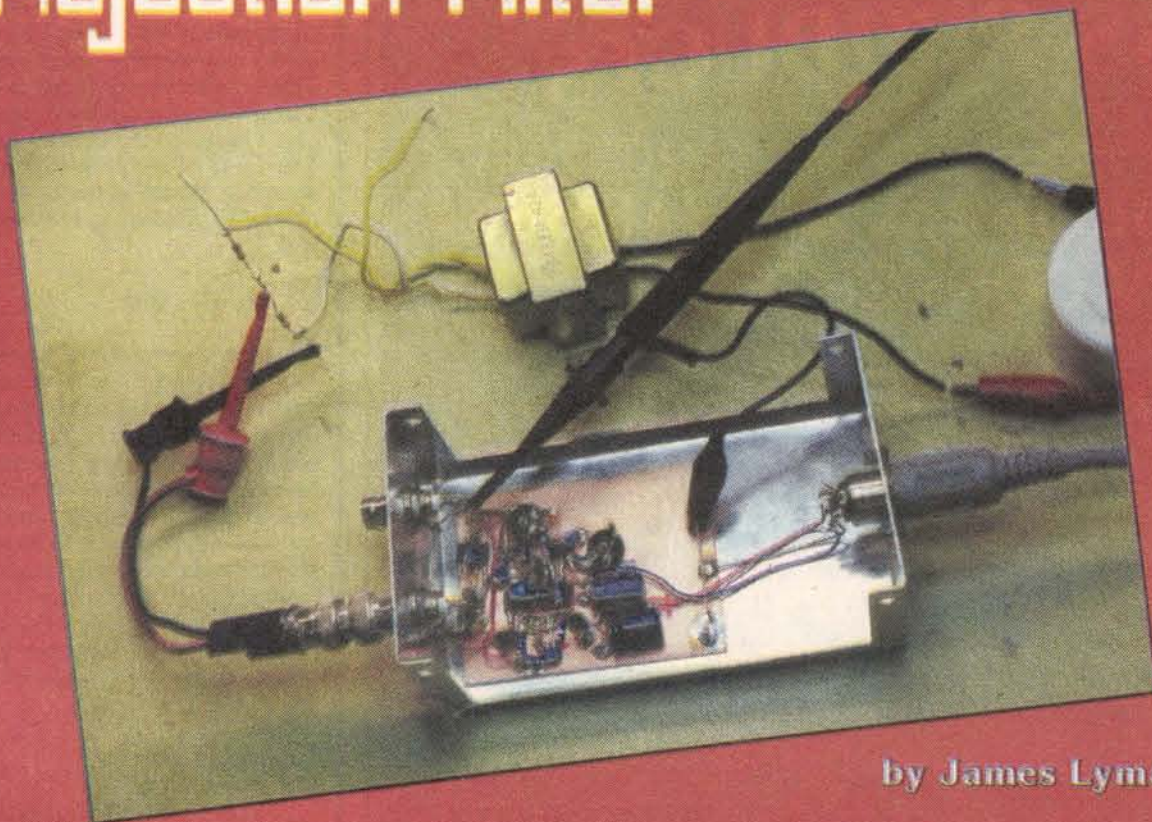


# An Easy Hum Killer



## A Deep Notch 60 Hz Rejection Filter



by James Lyman

In instrumentation, all of us have encountered one common problem, one that continually surrounds us in the world we live in — 60 Hz noise.

The penalty for all our modern conveniences is the AC power they use which surrounds us and continually radiates 60 Hz electromagnetic waves. These 60 Hz waves are usually strong enough to easily creep into low-level voltage signals we are trying to capture; showing up as noise that often is many times greater than the signals we are seeking.

When these signals are audio, we hear a constant low-frequency tone mixed with the audio we want to hear. This AC noise or hum can be disconcerting, and for something like music, is damaging in the sense of destroying the aesthetic qualities of the music.

Removing that AC noise without altering the signal requires a filter which rejects a small band of frequencies around 60 Hz without affecting other frequencies above or below the rejection band. This type of filter is called a band rejection filter.

This article describes a modular instrument which uses the common power supply described in the June 2000 issue of *Nuts & Volts* (pages 87-90, "Modular Instrument System").

A modular instrument is a simple instrument built in a stand-alone case, but having its power supply in another case which the instrument connects to using a five-pin DIN connecting cable such as RadioShack's part number 42-2151.

While this article describes the 60 Hz notch filter as a modular instrument, the basic filter circuit may be incorporated into other circuit designs requiring rejection of 60 Hz AC noise, such as audio applications.

If you have an audio recording with a 60 Hz hum, you can use this filter to drastically reduce that hum without compromising the audio itself, because this filter has a band width of only a few Hertz. This circuit is an active filter design that uses carefully-selected values of resistors and capacitors to determine the frequency of rejection.

### Designing the Filter

Whenever I design an active filter, I go to the book that's the holy grail of designing active filters — *Rapid Practical Designs of Active Filters* by Johnson and Hilburn<sup>1</sup>. I bought this book while working on my EE degree, a time long ago that I won't confess to here, and have used it ever since with great success. I've used other books, good books I might add, as well as various computer programs. But I get the best results from using this book, an important consideration at an earlier time before we had computer simulators for electronic circuits.

As its name implies, this book gives the designer the tools to quickly design a wide range of active filters, up to an eighth order, by first selecting a basic capacitor and the cutoff frequency. The designer chooses the type of filter his circuit requires, such as a low pass forth order Chebyshev with 2 dB ripple, then goes to the appropriate table to calculate the component values.

I have designed a number of different low pass, high pass, and band

|                      |                                             |
|----------------------|---------------------------------------------|
| $f_c := 60$          | Center frequency in Hz, for rejection       |
| $Q := 20$            | Quality factor of filter                    |
| $C := 0.1$           | Capacitor in uF, frequency tuning           |
| $G := 1$             | Filter gain, voltage ratio                  |
| $B := \frac{f_c}{Q}$ | Relationship of bandwidth to quality factor |

$B = 3$  Filter bandwidth in Hz

$K := \frac{100}{f_c \cdot C}$  Filter scaling factor

$K = 16.667$

$R_1 := 1.592 \cdot K \cdot \frac{Q}{G}$  Resistor R1 in Kohms

$R_1 = 530.667$

$R_2 := 1.592 \cdot Q \cdot K$  Resistor R2 in Kohms

$R_2 = 530.667$

$R_3 := 1.592 \cdot K$  Resistor R3, R4, and R5 in Kohms

$R_3 = 26.533$

$R_6 := 1.592 \cdot \frac{K}{G}$  Resistor R6 and R7 in Kohms

$R_6 = 26.533$

"Rapid Practical Designs of Active Filters,"  
David E. Johnson and John L. Hilburn,  
John Wiley & Sons, Inc., New York, NY, 1975.

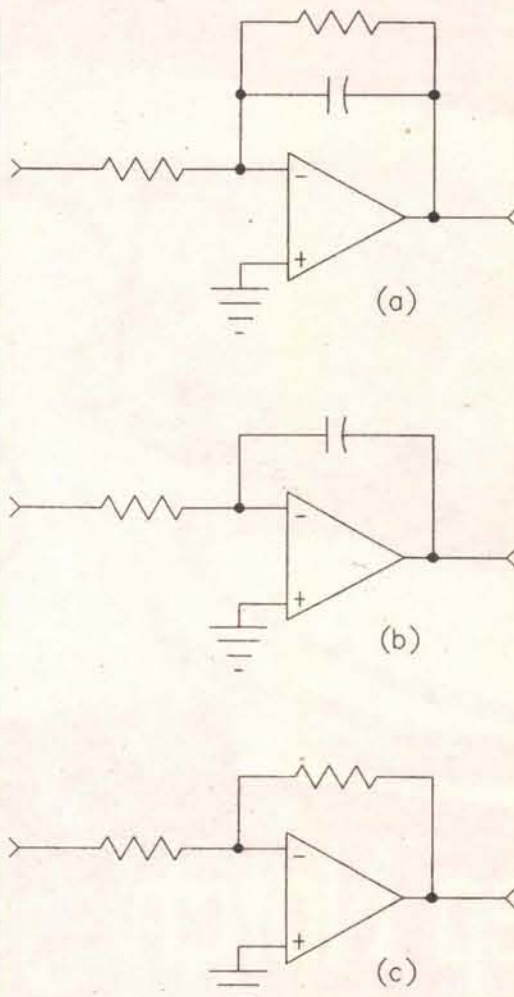
**Figure 1:  
Filter  
Calculations**

pass filters using these tables, but band reject or notch filters are another matter — they tend to be a bit twitchy, especially if you want very

narrow bands of rejection.

My first design was a Voltage Controlled Voltage Source (VCVS) band rejection filter using the book's

**Figure 2: Circuit Modules**



design procedure (page 210). This involved selecting the desired center frequency, bandwidth, and capacitor values, then performing some simple calculations to give the resistor values. These calculations are given in the book and only involve substituting and

doing the arithmetic which can be done with any calculator. But when the circuit was simulated with Electronic Workbench<sup>2</sup>, I was surprised to find its center frequency way above the designed value and spent considerable time in determining resistor values to give a center frequency of 60 Hz.

The simulation never gave a narrow bandwidth design, but rather one with -3 dB points of about 35 and 75 Hz which would corrupt much of the data from a transducer. Although the VCVS design uses the fewest components for a second order filter, its predicted performance was unacceptable.

I then tried the Multiple-Feedback band reject design on page 213. This circuit is more complex than the VCVS requiring three additional resistors and a second opamp. Again, I simulated the design using Electronic Workbench and found its response so completely unacceptable, I didn't pursue it further.

I next tried the notch filter design in Don Lancaster's filter book<sup>3</sup> which uses a summing amplifier to take the outputs

from an active low pass and high pass filter whose cutoff frequencies are selected to form a notch. Simulations of this design showed it having a wide bandwidth and a low level of rejection that is on par with the VCVS design but requiring considerably more parts.

Surprised that these designs were performing so poorly, I finally tried the Biquad band reject filter design, as outlined on page 215 and, despite the complexity of the circuit, I was surprised how well this circuit performed. This is definitely the circuit to use if you're serious about band rejection filters. I designed the filter for a gain of 1 and a Q of 20, where Q is the quality factor defined as the center frequency  $F_c$ , divided by the bandwidth BW.

$$Q = F_c / BW$$

Simulation showed its pass band to be extremely flat with an upper limit of 1 MHz. By adding two trimmer pots, the center frequency can be fine tuned to exactly the desired center frequency and the notch for maximum depth of rejection. Since the purpose of this filter is to reject 60 Hz power line noise, the fine-tuning ability allows you to make this circuit near ideal. The filter's performance is tolerant of component variations with no great changes in response from small changes in components.

#### The Design

To get good performance from active filters, you need to use close tolerance capacitors which are rather

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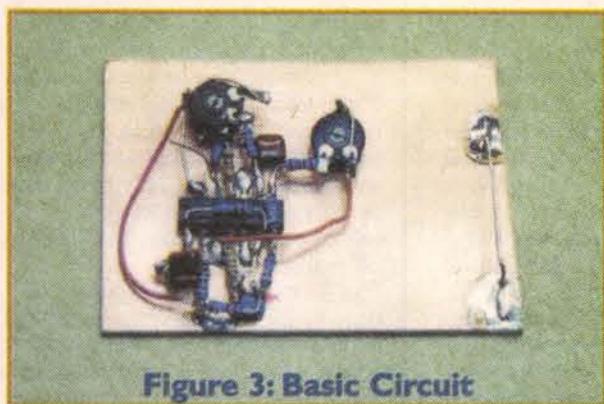


Figure 3: Basic Circuit

expensive and hard-to-find. Note — this does not apply to any of the power supply decoupling capacitors. The alternative to buying these is to measure capacitors and select the ones nearest the actual value. Anymore, capacitor meters are an inexpensive instrument often found in digital multimeters, so selecting capacitors is easy. Of course, the more capacitors you have, the easier it is to find accurate capacitors.

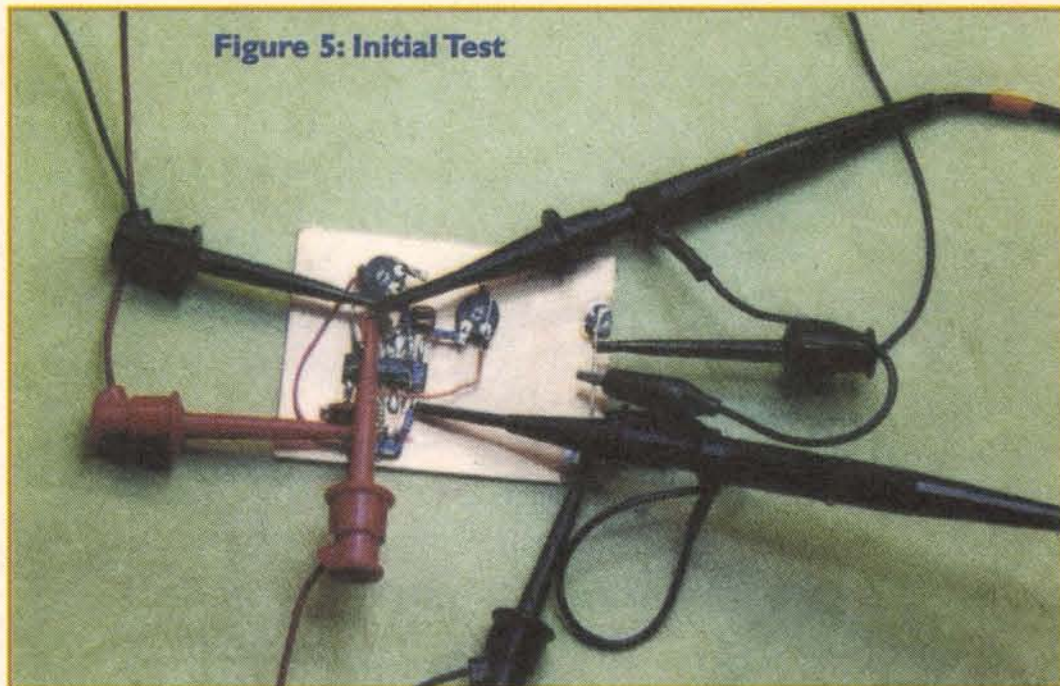
For me, the 0.1 uF capacitor is my most widely used value and therefore, I have a large number of them in inventory, so consequently I chose this value for my design.

The first step in the design is to calculate the scaling factor K which is used to scale the resistor values. This scaling factor is 100 divided by the product of the chosen capacitor value in microfarads times the center frequency in Hz.

The designer must choose two other parameters before calculating the resistor values — the over-all volt-

age gain of the filter and the bandwidth in terms of the quality factor Q. Since I wanted the maximum frequency response, which is limited primarily by the gain bandwidth product of opamps, I chose a gain of 1. A quality factor Q of 20 will give a bandwidth of about 3 Hz, a value I considered having a minimum effect on signal quality together with the scaling factor; the frequency and the quality factor determine the resistor values by using simply addition, multiplication, and division with a calculator. The book gives a simple formula for each resistor. For those readers who use Mathcad<sup>®</sup>, I have enclosed a Mathcad 6 file with the design calculations for a biquad notch filter that you can use in designing other notch filters with different parameters. The name of the file is bq60n20.mcd. A sample Mathcad

Figure 5: Initial Test



printout of this design is shown in Figure 1.

I entered the filter design into Electronic Workbench using the exact calculated component values and the generic opamp model. The circuit was simulated using the bode plotter to test the frequency response which allowed me to quickly measure the -3 dB points, the center frequency, and its signal rejection in dB. The frequency difference of the -3 dB points gives the filter's bandwidth in Hertz. Next, I replaced the exact calculated resistor values with standard 1% resistor values and simulated the circuit again.

The filter's response changed lit-

tle indicating the circuit is not very sensitive to component variations. Although the response was very good using standard values, I experimented and found those resistors which affected the center frequency and the depth of the rejection notch.

By replacing those resistors with the next lower standard values in series with a 1 Kohm trimmer potentiometer, I was able to exactly tune the simulated filter to 60 Hz with a very high rejection of about -50 dB. The Electronic Workbench circuit file is provided on Nuts & Volts web site for downloading by users who wish to further analyze this circuit. The file

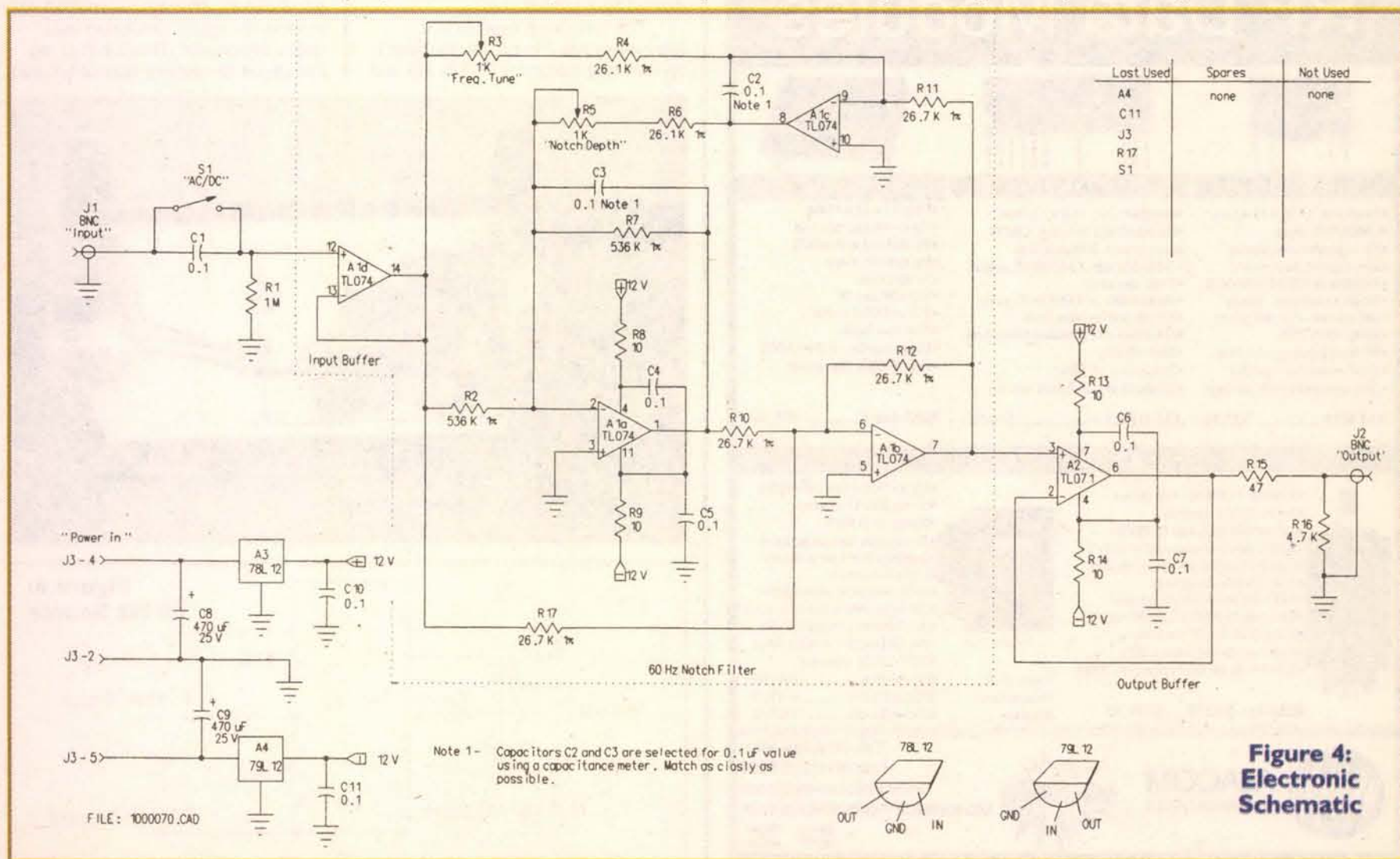


Figure 4: Electronic Schematic

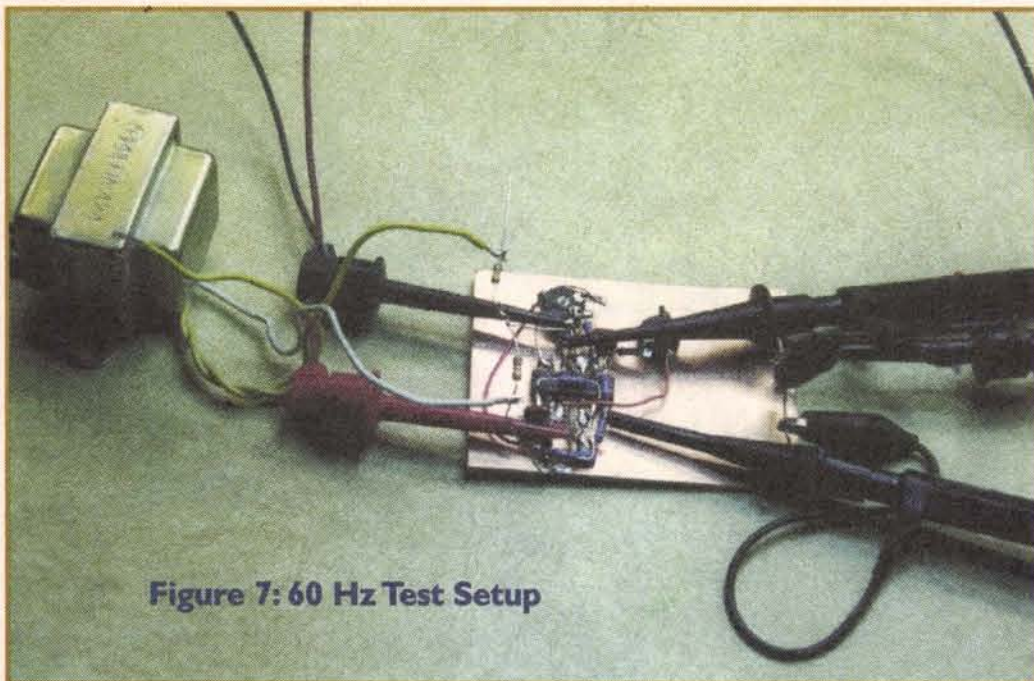


Figure 7: 60 Hz Test Setup

name is bq60n20.ewb.

### The Circuit

The biquad circuit gets its name from its transfer function which has two quadratic functions in it. A transfer function is the algebraic expression which relates the input and output of a circuit. A circuit's transfer function can be calculated — if the experimenter is so inclined — by using the basic frequency expressions for capac-

itors and inductors combined with resistors. But since this involves one or more college courses to learn, we'll forgo discussing how it's done. The point is the transfer function for a biquad circuit has two quadratic functions, hence the "bi" for two and "quad" for quadratic, where quadratic means an equation in the form:

$$y = ax^2 + bx + c$$

However, unless you're a glutton

for punishment, don't worry about it. That's why we have circuit simulator programs on our computers — so why all the discussion on transfer functions then? Well, the circuit of this filter is actually an analog computer<sup>5</sup> which is configured for the filter's transfer function.

For those who have known personal computers since their first memories, analog computers were once used when digital computers filled a large room, but had little more power than today's programmable calculators. Analog computers are composed of circuit modules which perform basic math functions such as addition, subtraction, multiplication,

and even calculus functions such as derivatives and integration.

General-purpose analog computers were programmed by using patch cords to interconnect those modules and other components, while numbers were represented by voltage levels. Analog computers were used to model complex dynamic systems such as orbiting bodies and vibrating structures, such as an aircraft's wing.

As an analog computer, the biquad circuit uses three circuit modules that are shown in Figure 2, which, when connected together with a feedback path, gives the basic transfer function of one quadratic equation divided by a second one.

The first circuit module is the lossy integrator (Figure 2a), the next is an inverting integrator (Figure 2b) and

finally the inverter of Figure 2c. By arranging these modules in slightly different order with feedback, the analog computer can represent the quadratic transfer function of a low pass, high pass, all pass, band pass, or band reject filter while selecting the values for resistors and capacitors will determine the filter's frequency response, in particular, the filter's cut-off frequency.

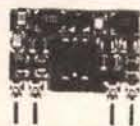
As expected, the input signal goes to the analog computer's input while its output provides the now filtered signal. As the input signal enters the analog computer, it is multiplied by the computer's transfer function and exits the computer's output having been modified; and since the transfer function is frequency dependent, different frequency components are modified by different amounts which results in the filtering action.

Calculating the required transfer function for a desired filter and then determining the values for the circuit components to give that transfer function is a somewhat tedious exercise in algebra, but *Rapid Practical Designs of Active Filters*<sup>1</sup> has already done the work for you so you only need to enter the filter's cutoff frequency and the value of the capacitor to quickly design a filter. But for those readers who wish to further explore this class of filters, M. E. Van Valkenburg's book *Analog Filter Design*<sup>6</sup> has a full chapter on the biquad circuit, chapter 5, titled "The Biquad Circuit."

### Construction and Testing

I was very curious if I could actually achieve -50 dB rejection with the actual circuit, although I suspected not because the circuit simulation uses ideal components. This is not to say that circuit simulations cannot be used

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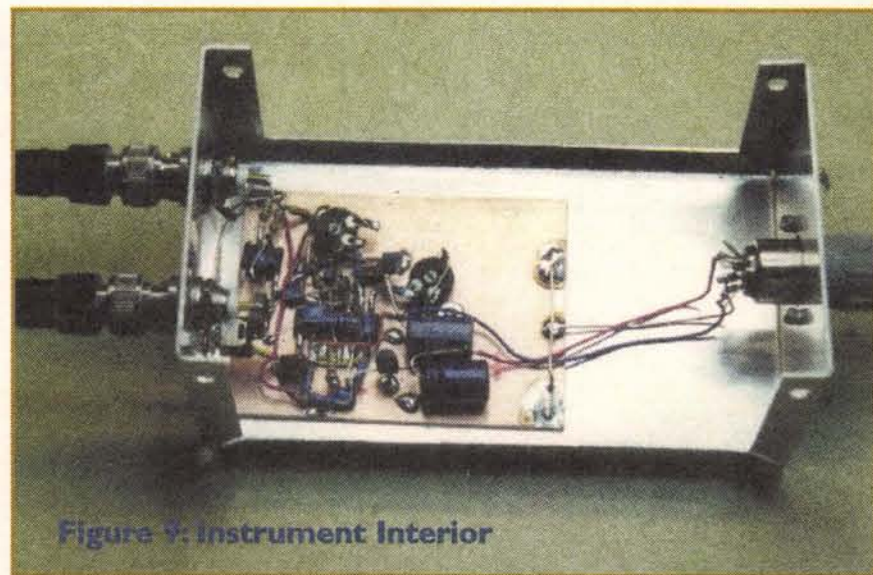


Figure 9: Instrument Interior

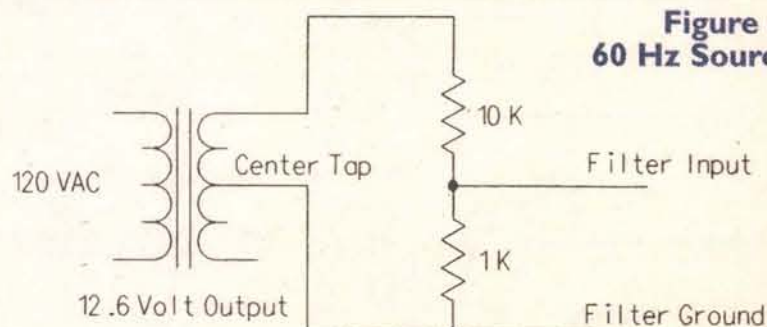


Figure 6:  
60 Hz Source

or trusted, but rather they must be tempered by your experience in electronics.

Like any other tool, such as your oscilloscope or voltmeter, it has its limitations in accuracy. To test the filter's performance, I built the instrument in two stages — the first stage was the basic filter itself which could be tested in the lab, the second as the full instrument to be used with the modular power supply.

I built the basic filter circuit first to test the circuit's performance before putting the time, material, and effort into the full instrument — better to know it will work satisfactorily before fully investing in it. The circuit was constructed on a piece of blank circuit board which fits into an aluminum P-box enclosure sold in RadioShack stores. This is a 2 x 3 x 5 inch box, part number 270-238, selling for about \$3.00, that makes an ideal case for modular instruments. My board measures about 2-1/4 x 3 inches and, as seen in Figure 3, the filter is built at one end.

Opamp A1 has all its leads bent outwards level with the chip so they don't touch the bare copper ground plane. Refer to Figure 4. Begin construction with the power supply decoupling network, R8, R9, C4, and C5, by cutting one lead of R8 to 1/4 inch and soldering it to pin 4 of A1. Now cut and form the leads of C4 to straddle the chip's body and solder it between pins 4 and 11 of A1.

Wrap one lead of C5 around a lead of R9 close to the resistor's body, then solder and cut the lead of R9 which has C5, to a length of 1/4 inch and solder that end to pin 11 to complete the network.

I placed the two high-frequency decoupling capacitors C10 and C11 on the free ends of R8 and R9 by looping a lead around the resistor's lead, soldering and trimming the capacitors leads flush. Trim the free ends of capacitors C10 and C11 to 1/4 inch length and then bend the resistor's leads up into a loop to allow connecting test leads for power.

With the network completed, you can position A1 on the circuit board and attach it by soldering the free ends of capacitors C10 and C11 to the circuit board. A1 has three opamps that connect to ground so use a small screwdriver to push pins 3, 5, and 10 down flush with the circuit board then solder each to the copper surface.

Now complete the basic filter circuit by installing those parts within the dotted box of the schematic diagram in Figure 4. Note that capacitors C2 and C3 are part of the frequency determining network of the filter, so their value is critical.

Precision capacitors are both expensive and hard to obtain, so use a capacitance meter to cull your stock of 0.1 uF capacitors and select the exact value. Although you want the value as near to 0.1 uF as you can get, the really important thing is for the capacitors to be matched, because the closer the capacitors are matched, the better the filter's performance.

Prior to testing, tack solder a short bare wire on pin 12 of A1 for attaching a test lead to inject the test

signal; note that the input network S1, C1, and R1 are not needed for initial testing, as well as the output buffer amplifier A2. If there is insufficient room to clip an oscilloscope probe to pin 7 of A1, you may need to also tack solder a short length of bare wire onto pin 7 to form a test point.

Trimmer pots R3 and R5 are single turn printed circuit board mount trimmer resistors with their leads bent upwards. Use epoxy to glue a small bit of insulating material — such as part of a wooden toothpick — under each resistor to prevent accidental shorting to ground when adjusting. Be careful not to glue any moving parts on the bottom of the resistor since this will prevent their adjustment. Finally, use a length of #20 AWG bare buss wire, then form and solder a ground bar to the copper foil at the opposite end for attaching ground leads.

For testing, use a split power supply, setting its output to  $\pm 12$  volts, with the positive rail going to R8, the negative to R9, and the ground lead to the ground bar. The circuit will pull less than 15 milliamps on either rail, so if greater than 15 milliamps disconnect, find the mistake before continuing.

Connect your function generator's output and one channel of your oscilloscope to pin 12 of A1 and adjust the level for about 1/2 volt pp sinewave at a frequency of about 200 Hz. Connect the other oscilloscope channel to the filter's output at pin 7 of A1 as in Figure 5.

If your filter is working correctly, the input and output levels will be the same amplitude. Now adjust the frequency to 60 Hz and the output amplitude should drop in level. Adjust resistors R3 and R5 for minimum amplitude, then sweep the frequency between 30 and 100 Hz. As you

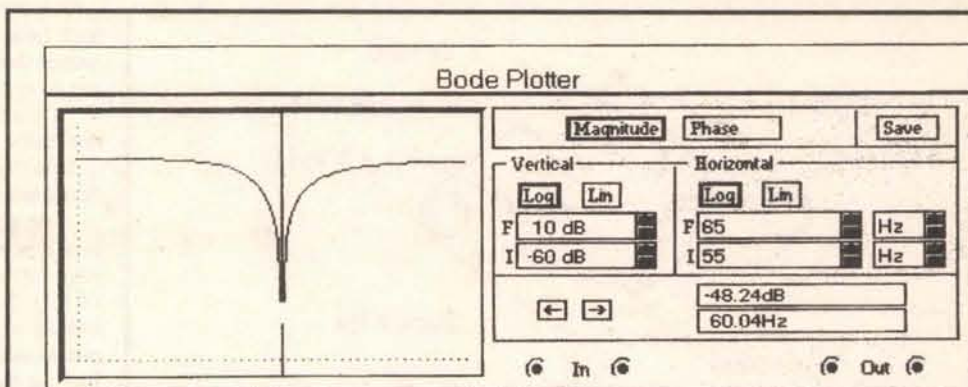


Figure 8: Electronics Workbench Filter Response

sweep across 60 Hz, the output amplitude will go very low while the input remains the same, but on either side of 60 Hz, the output will return to the same amplitude as the input.

In doing this test, you will undoubtedly have trouble setting your function generator to precisely 60 Hz and, since this filter has a bandwidth of only a few Hertz, it's critical to have a precise 60 Hz signal. This is very easily done since your lab has a very precise 60 Hz frequency source available — the AC power in the wall socket that your instruments are plugged into. The AC power in your home is set very precisely to 60 Hz and since you are using this filter to remove 60 Hz noise from signals, it's exactly what you should use to set up your filter.

All that is required is a six-volt filament transformer and two resistors to form a voltage divider to give a 1/2 volt output signal. For six volts, a 1 Kohm and 10 Kohm resistor will give this signal, but if you have a 12-volt transformer use a 22 Kohm in place of the 10K. Remember, if you are using a center tapped transformer, use one side and the center tap. Refer to Figure 6 for the schematic and tack solder the resistors to the transformer's leads, then check its output with the oscilloscope. This output signal can be connected to the filter by

either using test leads, by soldering short lengths of wire for jumpers, or by tack soldering the transformer's leads directly to the filter as in Figure 7. Again, while monitoring the filter's output, adjust R3 and R5 to give a null, that is, a minimum output signal. My filter gave a rejection of about -25 dBV which is calculated by:

$$\text{Rejection, dBV} = 20 * \log_{10}(\text{Vout} / \text{Vin})$$

Vin and Vout can be RMS, peak volts, or peak-to-peak volts — the only restriction is they must be the same units. If you're using a DVM for measuring, its AC scale should be true RMS since the output waveform at center frequency is complex instead of a sinewave. The -25 dB rejection is about half the rejection obtained by analysis using Electronics Workbench, but if you move the bode plot cursor in Electronics Workbench just a fraction of a Hertz from the center frequency, the rejection quickly approaches the real filter's performance. Refer to Figure 8.

The notch at the center frequency becomes extremely sharp which does not occur in the real world. When the span of the bode plot is set from 59 to 61 Hz, a change of 0.01 Hz from center frequency gives a change in notch depth of 10 dB. Furthermore,

| Ref. Desg. | Qty. | Nomenclature                                             | Part Number |
|------------|------|----------------------------------------------------------|-------------|
| A1         | : 1  | : TL074 Quad Bi-FET Op-Amp, 14 pin DIP                   | : note 1    |
| A2         | : 1  | : TL072 Dual Bi-FET Op-Amp, 8 pin DIP                    | : note 2    |
| A3         | : 1  | : 78L12 +12V, 100 mA, 3 Terminal Voltage Regulator, TO92 | : note 3    |
| A4         | : 1  | : 79L12 -12V, 100 mA, 3 Terminal Voltage Regulator, TO92 | : note 4    |
| C1-7,10,11 | : 9  | : 0.1 uF Monolithic Bypass Capacitor, 25V                | :           |
| C8,9       | : 2  | : 470 uF Electrolytic Capacitor, 25V                     | :           |
| J1,2       | : 2  | : BNC Panel Mount Bulkhead Recept, Solderable            | : note 5    |
| J3         | : 1  | : 5 position DIN Receptacle, Panel Mount                 | : note 6    |
| R1         | : 1  | : 1 Mohm Resistor, 5%, 1/4 Watt                          | :           |
| R2,7       | : 2  | : 536 Kohm Resistor, 1%, 1/4 Watt                        | :           |
| R3,5       | : 2  | : 1 Kohm Potentiometer Resistor, Single Turn             | :           |
| R4,6       | : 2  | : 26.1 Kohm, 1%, 1/4 Watt                                | :           |
| R8,9,13,14 | : 4  | : 10 ohm Resistor, 5%, 1/4 Watt                          | :           |
| R10-12,17  | : 4  | : 26.7 Kohm Resistor, 1%, 1/4 Watt                       | :           |
| R15        | : 1  | : 47 ohm Resistor, 5%, 1/4 Watt                          | :           |
| R16        | : 1  | : 4.7 Kohm Resistor, 5%, 1/4 Watt                        | :           |
| S1         | : 1  | : SPST Micro Miniature Toggle Switch, Panel Mount        | : note 7    |
|            | : 1  | : Aluminum P-box, 2 x 3 x 5 inches                       | : note 8    |

note 1 - Digi-Key part number 296-1777-5-ND  
 note 2 - Digi-Key part number 296-1775-5-ND  
 note 3 - Digi-Key part number NJM78L12A-ND  
 note 4 - Digi-Key part number NJM79L12A-ND  
 note 5 - Digi-Key part number ARFX1064-ND  
 note 6 - Digi-Key part number 275-1014-ND  
 note 7 - RadioShack part number 275-624  
 note 8 - RadioShack part number 270-238

## PARTS LIST

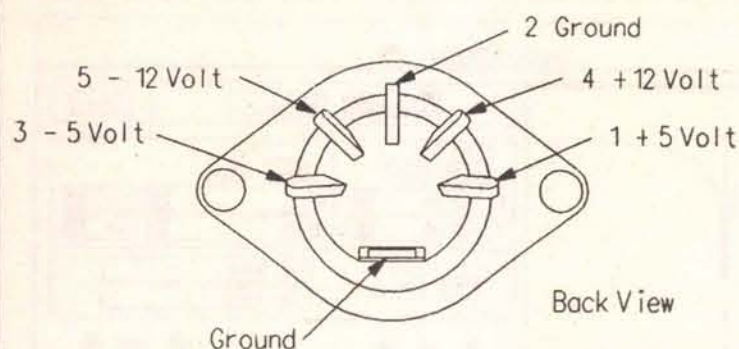


Figure 10: Power Connector

the depth of the notch varies with the settings of the bode's start and stop frequency, another indication that we are looking at a mathematical artifact instead of real-world performance.

If testing shows the basic filter to be working correctly, continue building the instrument by installing the output buffer amplifier A2 and the input network C1 and R1. Again, start by installing the power decoupling network R13, R14, C6, and C7 to opamp A2, then position the assembly on the circuit board and solder the free end of C7 to the circuit board. Install the DC return network R15 and R16 then connect pin 7 of A1 to pin 3 of A2. You may want to do another test before finishing the power supply because, if there is a problem, you have more room to work without the clutter of the power circuits.

Install the filter's power circuits which consists of regulators A3 and A4 and capacitors C10 and C11. Start by spreading the input and output leads of A3 and A4, then bend the end (1/4 inch) of each ground lead 90 degrees and finally, solder the regulators to the circuit board via their ground leads.

Note that the schematic (Figure 4) has the pinouts for A3 and A4. Position the output of the regulators leads as near to the power input pins of A1 as possible. Complete the power supply by installing the two filter capacitors and then connect the regulator outputs to the circuit power using the regulator's output leads directly or insulated wire if the distance is too great.

You may want to test the circuit

before installing the board in its case by using a laboratory power supply. If so, be sure and set the power supply voltage at least three volts above the regulator's 12 volt output to ensure the regulators will correctly regulate.

### Case

When you are satisfied that your notch filter is working correctly, you can install it in the case, but I advise you to do all the sheet metal work first. This involves drilling holes for the three panel jacks and a toggle switch. The ends of the case's top are used as the instrument's front and rear panels. The input and output jacks J1 and J2 are panel mount BNC connectors which mount in 3/8 inch holes drilled in the front panel.

The "AC/DC" select switch S1 is mounted just above the input connector J1. The power connector J3 is mounted on the opposite end of the case's top in approximately the center. This connector is a five-pin DIN panel mount connector that requires a 5/8 inch hole that is too large to drill cleanly in such thin sheet metal, even if you have a drill bit that large.

This hole must be drilled smaller and expanded with a rat tail file until J3 will pass through the hole. If you are going to be doing very many of these, I strongly recommend investing in a chassis punch such as a 5/8 inch Greenlee round metal punch set, part number 500-2409.4. This punch allows you to drill a small hole, mount the two halves of the punch on either side with a bolt passing through the hole to connect the punch halves together, then by tightening the bolt

with a wrench, you cut a perfect 5/8 inch hole in the sheet metal. Much easier than fighting with a file and trying to get the connector to fit.

You can mount J3 using screws and nuts, but I find it easier to use 1/8 inch aluminum pop rivets which don't work loose.

As seen in Figure 9, the circuit board is mounted on the inside of the case top with the filter input (pin 12 of A1) close to the front panel which has J1 and J2. While holding the circuit board in position, drill a 1/8 inch hole at the center of the circuit board, through both the circuit board and sheet metal top cover, then use a 4-40 x 1/4 screw and nut to secure the circuit board in place.

With the circuit board secured, cut one end of the input resistor R1 to 1/4 inch, then bend the other lead 90 degrees about 1/4 inch from the resistor's body. Solder the straight part of R1's long lead to pin 12 of A1 with the bent part of the lead pointing upwards. The resistor's body should be in line with pin 12 and laying against the circuit board.

Now press the short lead of R1 against the circuit board and solder it to ground. Finally, the lead of R1, which is pointing upwards (pin 12 of A1), is connected to one side of the switch S1 ("AC/DC") and soldered. Connect a wire from the other side of switch S1 to the center terminal of J1 ("Input") and solder both ends.

The bypass capacitor C1 is connected across switch S1 by soldering its leads to the leads already connected to switch S1. For the filter's output, solder a wire from the junction of R15 and R16 to the center terminal of J2 ("Output").

Finally, connect the +12 volts of J3 (terminal 4) to the input lead of regulator A3 and the -12 volts of J3 (terminal 5) to the input lead of regulator A4 using insulating wires. Connect the grounds of J3 (terminal 2 and Ground) to the copper foil of the circuit board using either insulated or bare buss wire. Refer to Figure 10 for terminal locations. Your instrument is now ready for use.

Make a final test and adjustment of the filter by connecting the input of the notch filter to the signal source shown in Figure 6, 60 Hz Source, and the filter's output to an oscilloscope or

voltmeter. Again, adjust R3 and R5 for minimum signal level which gives you the highest rejection of 60 Hz noise.

If you need higher rejection, you can cascade additional notch filters together with each additional filter giving you another 25 dB rejection, but remember you can't reach extremely low levels of 60 Hz noise because the noise will re-enter your signal from other sources.

Now you have another modular instrument which I'm sure you'll find to be a useful addition to your lab. Note that for AC hum noise coming from power supplies that have full-wave rectifiers, the noise will be 120 Hz instead of 60 Hz. Filtering this noise will therefore require a notch filter designed for a center frequency of 120 Hz. NV

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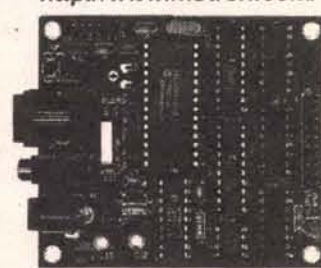
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